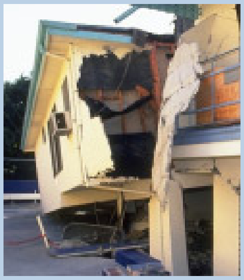
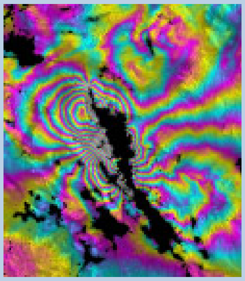
GESS

GLOBAL . EARTHQUAKE . SATELLITE . SYSTEM

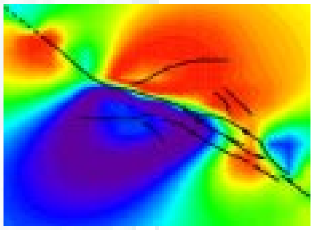
A 20-YEAR PLAN TO ENABLE EARTHQUAKE PREDICTION

MARCH 2003





Scientific Motivation



CHAPTER TWO

The requirements for a global earthquake observational system are derived from current scientific understanding of earthquake physics, crustal rheology, and fault interactions, the societal benefits of defining and mitigating seismic hazard, and aiding in disaster response following large earthquakes. In simple terms, earthquakes are generally viewed as being one component of a longer cycle in which a given section of a fault accumulates stress due to plate tectonic driving forces, releases that stress during an earthquake, and then begins the cycle anew. Since these time scales are on the order of seconds for the coseismic portion and centuries for the interseismic phase, we rarely observe a complete cycle. When multiple events do repeat on a given fault segment, significant variation in time scale and earthquake size is the rule. Further complicating our understanding of earthquakes is that they do not occur in isolation. Earthquakes located nearby in space and time induce additional forces into a given fault system, either through the static stress changes induced coseismically, or through temporally evolving postseismic stress changes. Since seismology is essentially confined to the coseismic realm, geodesy is the principal means of measuring the response of the fault and lithosphere during the inter- and postseismic part of the earthquake process. GPS networks have already had a tremendous impact on understanding the earthquake cycle. A space-based system for monitoring crustal deformation is the logical next step to achieve revolutionary advances in earthquake science needed to develop a better predictive capability.

Inset: Modeled seismic cycle deformation. (Rundle and Kellogg, 2002)
Background: Interferogram from Antofagasta, Chile, earthquake. (Pritchard et al., 2002)

GESS Science Investigations and Requirements

The GESS science requirements derive directly from the GESS investigations that addressed the current and future state of our understanding of earthquake physics, and the measurements necessary (and practical) to advance our understanding (see page 98). Some of the investigations present theoretical or scenario-based models that predict specific space–time behavior of seismicity and patterns of crustal deformation. These studies placed requirements on resolving different classes of lithospheric models and time scales of pre- and postseismic deformation. Other studies presented examples from the current principal satellite SAR system, the European Space Agency's (ESA) ERS satellites, which have formed the basis for much of our current understanding of SAR interferometry, both in terms of performance and in terms of the types of information and applications that are possible. These examples impact both the single image and interferogram data requirements, and also illustrate methods for overcoming some of the error sources through data stacking, time series inversion, or atmospheric modeling. Finally, applications goals such as earthquake disaster response also impact the system requirements.

Before examining the main scientific questions regarding earthquakes, it is worth summarizing how these pieces fit together and their historical context. Our current understanding and the direction we see as necessary to understanding the earthquake process are directly linked to the recent past. Much of our understanding of earthquakes comes from seismology, both in terms of their space–time magnitude, and from understanding the characteristics of the earthquake rupture kinematics and dynamics. Understanding coseismic rupture kinematics has benefited from the use of high-quality geodetic data, in particular the applications of InSAR.

Advances in GPS and InSAR data in conjunction with several significant earthquake sequences (Landers–Hector Mine, California; Izmit–Duzce, Turkey) in the 1990s provided important insight into their coseismic ruptures, and also provided important new observations and model constraints on complex ruptures, triggered earthquake sequences, and aftershocks. The Landers earthquake was the first application of InSAR to crustal deformation. Examination of the complex rupture and aftershocks of the Landers event stimulated development of models based on stress shadowing and stress migration in the crust and upper mantle to explain the space-time occurrence of these triggered events. The case was similar for the Izmit–Duzce and Manyi–Kokoxili, Tibet, earthquake sequences. High-quality space geodetic data (particularly from InSAR) allowed observation of spatial and temporal behavior of the crust following large earthquakes that forced re-examination of the crustal response and the forces governing earthquakes.

The insights gained from these event data sets have in turn boosted a debate regarding the time-varying state of stress in the crust, and have fueled fresh examination of the physics of the earthquake cycle on fault systems. Theoretical models that examine earthquake clustering and stress evolution predict spatial and temporal deformation signals that could be measurable with future satellite systems. This could lead to significant advances in our ability to constrain the locations of future earthquakes.

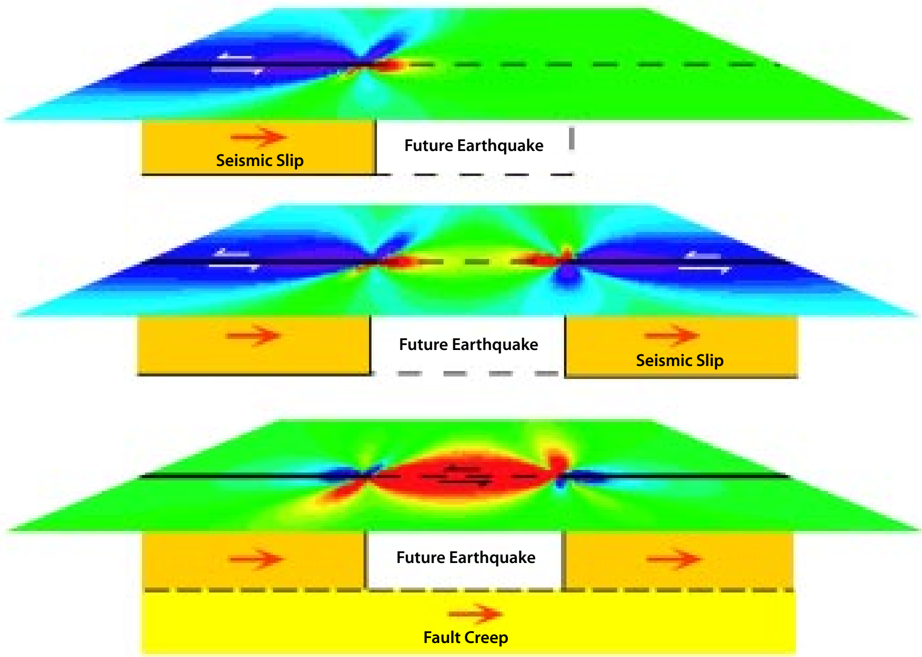


Figure 2.1
Evolution of Coulomb stresses prior to an earthquake. Each figure shows the progression of the surface Coulomb stress due to earthquakes and deep fault creep on a fault segment that will experience a future earthquake. Warm colors indicate that the change in stress favors a future earthquake. Thus, in addition to the steady-state tectonic loading of the future earthquake segment, the positive Coulomb stress caused by the surrounding fault segments increases the likelihood of an event on the future earthquake segment. (Sammis and Ivins, 2002)

Significant improvement in observation of earthquake crustal deformation provided by GPS and InSAR during the past decade placed critical constraints on some existing models and forced significant revision of others. Perhaps the most significant inference we can draw from these advances is that the feedback loop between data and models is critical, and that future advances will require better data, particularly InSAR data.

As stated in Chapter 1, we solicited studies to define requirements for an observational system that could address specific outstanding questions in earthquake science. The results of the studies are discussed here. In the following section, we have renumbered the original six study questions slightly, combining questions 3 and 4 to emphasize the relationship between complex and triggered earthquakes, and postseismic processes.

1. ***How does the crust deform during the interseismic period between earthquakes and what are its temporal characteristics (if any) before major earthquakes?***

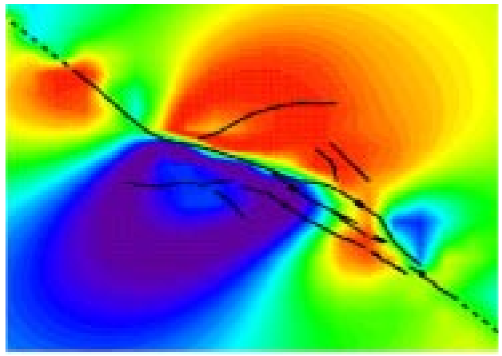
Detecting signals precursory to large earthquakes has been one of the most sought after and debated aspects of earthquake physics. Observations of precursory signals have been sporadic and often without a clear link to the subsequent earthquake. In the cases where the connection is clear, the measurements have generally been point location measurements, sometimes requiring measurement sensitivities that are not possible with satellite systems.

At the core of this debate is whether or not earthquakes are fundamentally predictable. Some have argued that the crust is continuously in a state of self-organized criticality (SOC) with the probability of earthquake size and location remaining steady. Sammis and

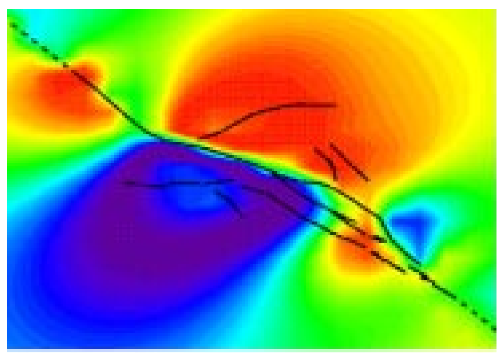
Ivins (2002) and Rundle and Kellogg (2002) argue, instead, that earthquake systems have "memory," with large earthquakes moving the crust away from SOC through "stress shadowing" (Fig-ure 2.1). This provides testable observations of seismicity and late seismic cycle deformation that could be measured both seismically and with radar interferometry (Figure 2.2). The stress shadow models for the earthquake cycle (Figure 2.1) predict that when the surrounding crust is moved away from SOC less background seismicity is expected, but as a future earthquake approaches an increase in surrounding activity should occur.

The basis for this model is the seismicity and stress shadow models derived for the large earthquake sequences of the 1990s described previously. The exciting aspect of these recent seismic cycle models is that they predict temporally and spatially varying deformation patterns in the termination regions of locked fault segments. These models can constrain earthquake fault system behavior, and should be of a magnitude measurable with radar satellite systems.

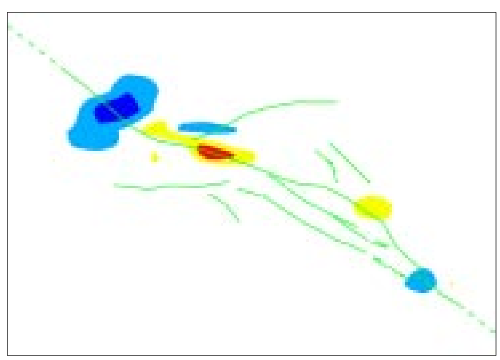
Part of the model for individual faults and fault systems consists of sections that experience either continuous or transient creep. Creep, or aseismic slip, describes slip on fault surfaces that does not produce seismic waves, or discernible shaking. While some creeping fault segments are recognized, and several such segments are monitored locally in well-instrumented regions such as California, many creeping faults are still unknown. InSAR is a valuable measurement technique for detecting and measuring the spatial and temporal characteristics of creeping faults (Figures 2.3 and 2.4), including strike-slip faults (Sandwell and



Five years pre-earthquake.



Five years postearthquake.



Difference.

Contour Interval = Radar Wavelength

Figure 2.2
Comparison of the predicted deformation due to stress buildup and release for a large simulated San Andreas earthquake, as observed by C-band InSAR. The bottom panel differences the pre- and postseismic signals to show the level of precursory deformation expected, defining the segment of the fault that will rupture. (Rundle and Kellogg, 2002)

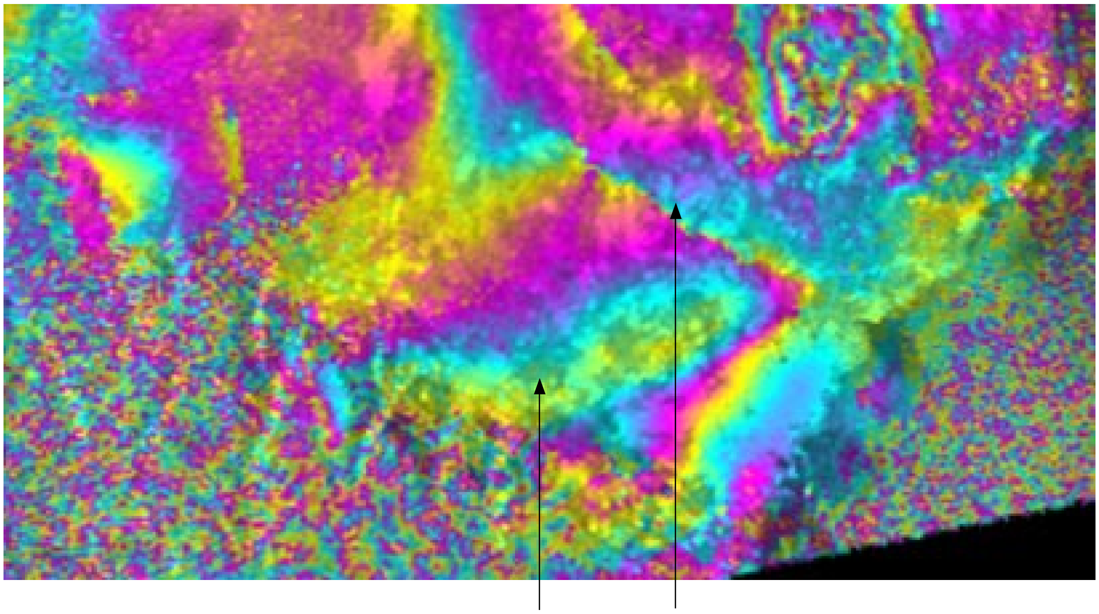


Figure 2.3
A portion of an interferogram at Mt. Etna, Italy, showing anticline growth and fault creep (data from 1993–1996, from ERS-1 and ERS-2, courtesy ESA). One color cycle represents 2.8 cm of surface displacement in the radar line-of-sight (LOS). Incidence angle for this image is approximately 23° from vertical toward the west-southwest. The anticline and fault both show approximately 3 cm of LOS displacement. (Lundgren, 2002)

Fialko, 2002; Burgmann et al., 2002; Lundgren, 2002) as well as blind thrusts (Lundgren, 2002). If the motion is steady, stacking (averaging) InSAR data can reduce many of the transient and systematic errors in a series of interferograms (Sandwell and Fialko, 2002). To detect variations in the rate of deformation, least-squares network inversions can be used to calculate an InSAR time series (Figure 2.4), with a relative deformation map at each InSAR data acquisition (Burgmann et al., 2002; Lundgren, 2002). To be able to detect any precursory deformation and to discriminate between even relatively simple models of locked versus creeping areas on faults requires a measurement accuracy of less than 1 mm per year (Zebker and Segall, 2002; Fielding and Wright, 2002).

Requirements

The requirements for detecting these signals requires both wide swath (on the order of 100 km), and detailed spatial sampling (10–100 m). Also required is long-term temporal continuity (over decades) but at fine enough temporal sampling (several days) that precursory phenomena can be separated from the coseismic, postseismic, and aftershock signals that accompany a large earthquake (i.e., Figure 2.2). Similarly, to monitor creep processes on faults, long time span interferograms (more than seven years) are most important for resolving rates at the 1 mm/yr level (Sandwell and Fialko, 2002). However, detecting transient deformation requires weekly or more frequent measurements to improve temporal resolution and reduce atmospheric noise.

2. How do earthquake ruptures evolve both kinematically and dynamically and what controls the earthquake size?

To start to address the question of when and where a future earthquake will occur, and how big it will be, requires an improved understanding of earthquake physics. This starts with more precise knowledge of the coseismic ruptures: how does the slip grow over the fault plane in both time and magnitude, and what controls these parameters? Questions encompassed by this include understanding how earthquakes nucleate and what causes them to stop.

Although answering this question has traditionally been the realm of continuum mechanics and seismology, surface deformation has increasingly played a part in improving kinematic and dynamic coseismic models. InSAR has provided detailed surface deformation maps that place tight constraints on the spatial distribution of slip on the fault plane, thus allowing seismic data to better define the temporal evolution of the slip when joint seismic and geodetic inversions are calculated (Olsen and Peyrat, 2002; DeLouis et al., 2002).

The location and slip vectors of the coseismic slip for large earthquakes are important in constraining the temporal characteristics of the earthquake rupture, thus defining the driving force for subsequent postseismic crustal response, afterslip, and the locations and sizes of aftershocks. High-density surface displacements as revealed through InSAR have been used over the past decade to place powerful constraints on coseismic slip maps. When combined with other seismic data, the resulting inverse models can image the propagation of the rupture in space and time, and place important constraints on the fault dynamics. Repeat orbit interferometry alone cannot meet the temporal requirements for directly imaging the seismic wave propagation and rupture dynamics near the fault. How-

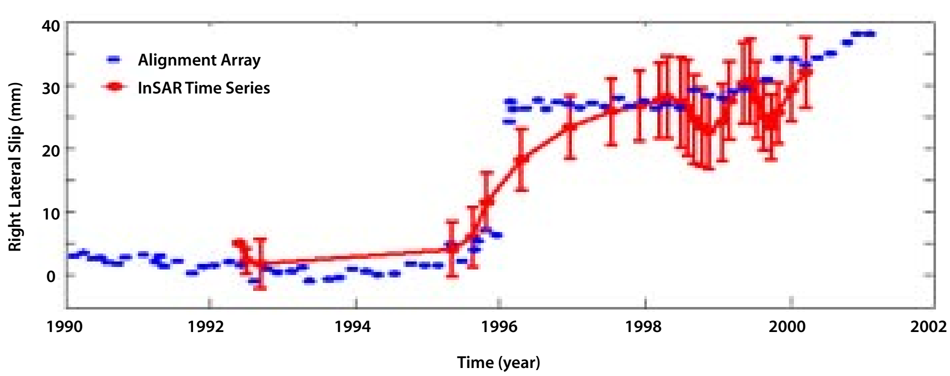
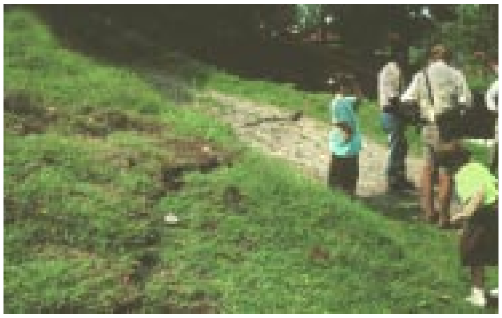


Figure 2.4
Observed surface creep across the southern Hayward fault in Fremont, California. Blue circles show alignment array data which captured a 2 cm creep event in February 1996. Red points display an InSAR time series where the change in range has been projected onto a fault parallel vector. The time series is the result of an inversion using 45 interferograms. Error bars represent the scatter in adjacent pixels. (Lienkaemper et al., 1997)



Izmut Earthquake

Duzce Earthquake

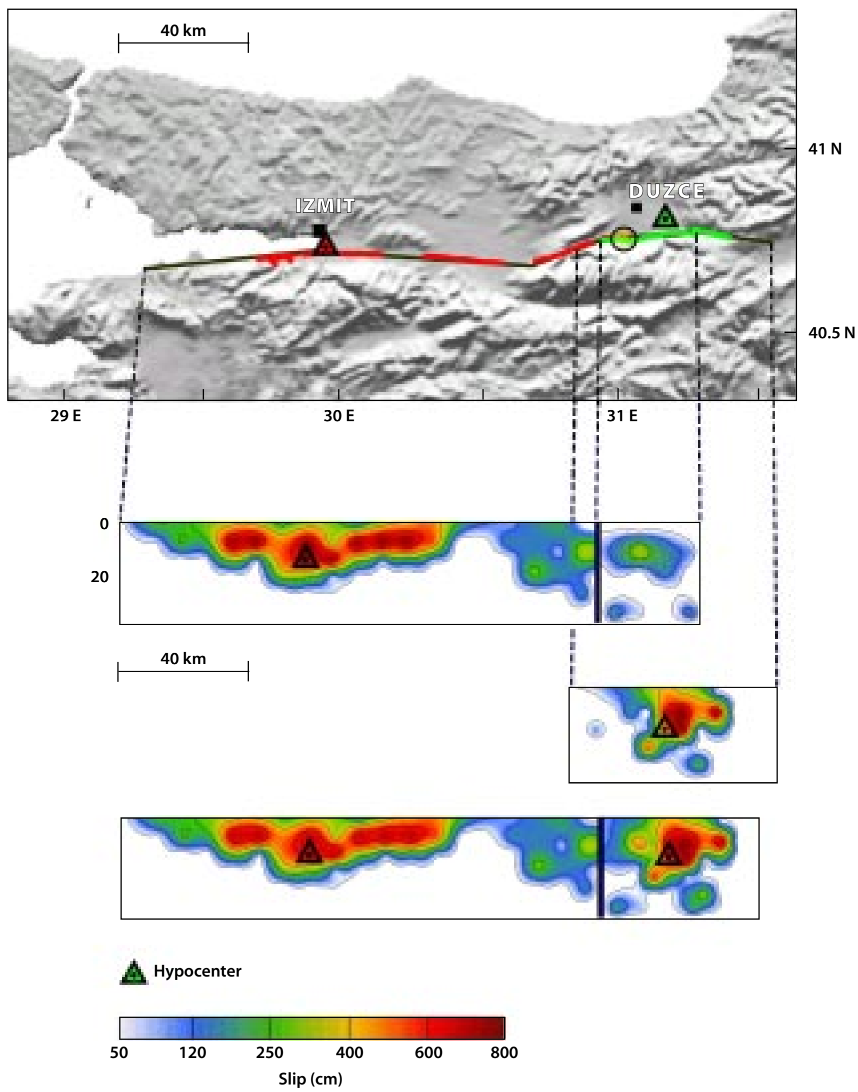


Figure 2.5

Complex slip and fault interaction for the 1999 Izmit–Duzce, Turkey, earthquakes (magnitude 7.5 and 7.3, respectively). The two photos are at the same location (indicated with a circle on the panel to the right). The photo on the left is the small fault offset at the eastern end of the Izmit rupture. The right photo shows the much larger normal fault motion that occurred during the Duzce earthquake (photos courtesy of the Seismological Society of America). Middle panel shows each earthquake's surface ruptures (red, Izmut; green, Duzce), hypocenters, and the traces of the modeled fault planes. The lower panels show the individual and combined slip on the fault planes. Notice how the Duzce slip area fills in the area immediately to the east of the Izmit rupture. The model was derived from the joint inversion of InSAR and seismic data. (Delouis et al., 2000) ever, coseismic interferograms do provide unprecedented images of the surface deformation. This allows creation of detailed models of the slip heterogeneity that help identify rupture asperities, or barriers, and the physical controls on earthquake rupture growth and termination. Slip maps, such as those for the Izmit–Duzce sequence (Figure 2.5) are important input parameters for models of stress loading on nearby fault systems.

Requirements

Coseismic InSAR requires coherent SAR images taken as soon as possible before and after an earthquake in order to minimize the effects due to postseismic and possible precursory deformation transients. Due to the large signal, atmospheric noise is not as corrupting an error source for large earthquakes. For earthquakes such as Izmit, cultivated, vegetated areas were problematic for maintaining correlation between interferograms of C-band ERS data (Fielding and Wright, 2002). This problem would be mitigated by both more frequent repeat data, and with L-band radar (Price et al., 2002). A repeat time of one to three days would be optimal, with a repeat of one week offering significant improvements relative to current systems.

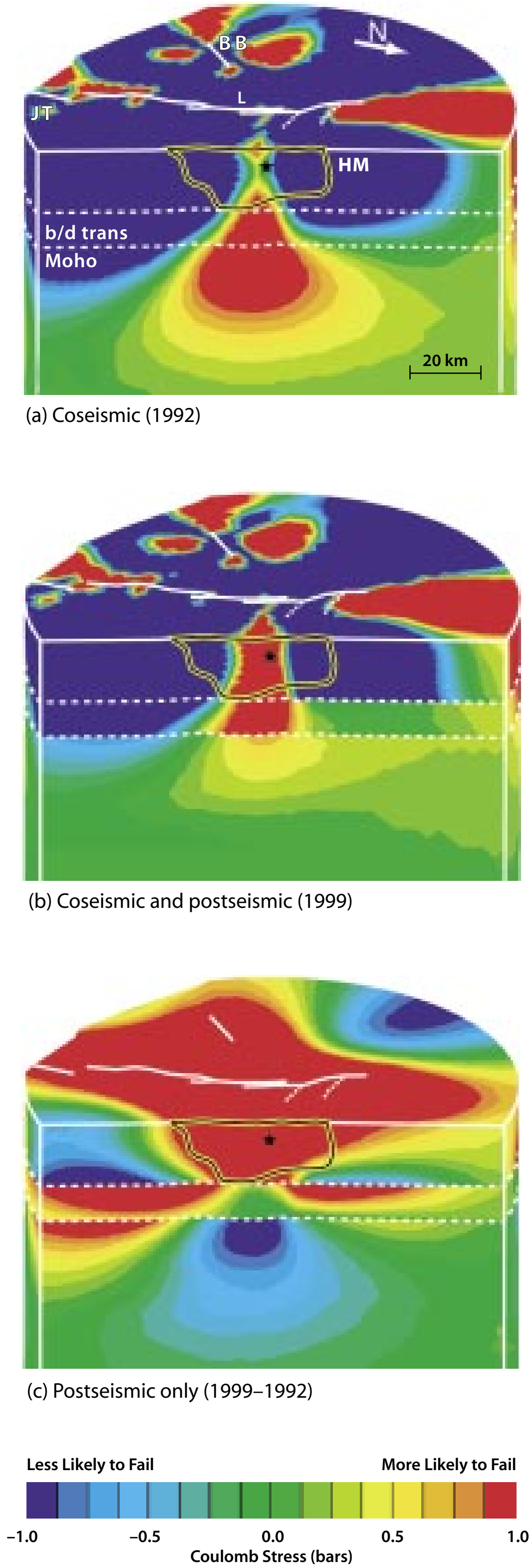
3. ***What controls the space–time characteristics of complex earthquakes, triggered earthquakes, and their aftershocks, and how are they related to postseismic processes?***

Many large earthquakes cluster in space and time. Understanding the process that accounts for an initial earthquake triggering secondary events may reduce hazards, and lead to more accurate forecasts.

The physical parameters that control the spatial and temporal separation of events are poorly understood, such as the seven-year delay of the Landers–Hector Mine earthquakes over the tens of kilometers separating these events (Figure 2.6), or the three months that separated the Izmit–Duzce sequence, whose coseismic ruptures overlapped. In addition to static stress changes caused by a large earthquake, stress rates caused by creeping faults or volcanic processes can also affect seismicity (Toda et al., 2002). Triggered earthquakes pose a significant hazard and are potentially the best candidates to constrain in space and time, since the master event provides the largest change in stress to the local fault systems. At the present, understanding of these events is hampered by incomplete knowledge of the pre-existing physical properties of the neighboring fault systems, and of the evolution of the crustal stresses over time scales of minutes to years that separate coupled earthquakes. The initial conditions cannot be directly measured at present. InSAR could provide detailed measurements of the coseismic and postseismic deformation that would place better constraints on stress diffusion models, and refinements of fault interaction models, that could lead to better-constrained predictions of triggered earthquakes.

Recent observations, principally driven by GPS and InSAR, have revealed complex and relatively fast (days to years) near-field postseismic crustal deformations. These measurements have refined understanding of the different processes (afterslip, poroelastic, viscoelastic) that play a role in the diffusion of stress, both along the fault plane and within the surrounding crust and mantle (Figure 2.6). The detailed, spatially continuous surface deformation measurements

Figure 2.6
Calculated coseismic and postseismic changes in Coulomb stress associated with the 1992 Landers earthquake sequence. (a) Calculated coseismic Coulomb stress changes shown both for the top ground surface and for a cross-sectional view of the model along the Hector Mine (HM) rupture surface (surface encompassed by black within yellow line). The Hector Mine hypocenter is shown as a black star. The Joshua Tree (JT), Landers (L), and Big Bear (BB) rupture surfaces are shown as white lines on the top ground surface. The lower crust lies between the brittle/ductile transition (b/d trans) at 18 km depth and the Moho at 28 km depth. (b) Calculated combined coseismic and seven years of postseismic Coulomb stress changes if viscous flow occurs predominantly in the upper mantle. (c) Calculated postseismic Coulomb stress changes due solely to viscous flow during the seven years following Landers (1992–1999). (Freed and Lin, 2001)



provided by InSAR are an important tool for recognizing these deformation patterns and interpreting the physical processes that cause them.

Requirements

To measure the rapid postseismic deformation and afterslip following a large earthquake (and between the triggered events) requires weekly revisit times. Because time scales of earthquake pairs can be from minutes to years, detecting changes in surface deformation requires similar time scales. Therefore, repeat measurements from one to three days would be better. The more frequent the measurements, the better we can understand earthquake and fault interactions more completely. In addition, frequent sampling allows for larger data sets. This improves signal resolution through stacking and time series computations that reduce the effects of atmospheric and other noise sources. Larger separations in time over greater spatial scales also dictate wide swath coverage over longer time periods, of order one decade. The subtle amplitudes seen for postseismic deformation associated with the Landers earthquake require resolution of deformation rates down to 1 mm/yr.

4. *How can we identify and mitigate local seismic hazard (such as liquefaction)?*

During an earthquake, the distribution of damage is not uniform and depends on the size and frequency of ground shaking, as well as other factors such as building construction. The reduction in loss of life and property, both during the earthquake and in the time following it, can be mitigated by understanding the areas that are most prone to severe damage, and in identifying the degree of damage as quickly as possible afterwards.

One important contribution of GESS to earthquake hazard assessment lies in the application of space-based technologies to response efforts by local and federal agencies immediately following a large earthquake. Identifying liquefaction is by definition a post-event analysis. Shinozuka et al. (2002) compared attempts at identifying liquefaction and the ability to differentiate between liquefaction and the effects of ground shaking as the cause of building damage for the 2001 Gujarat, India, and Izmit earthquakes. They found that for the large rural areas of the Gujarat earthquake, the well-documented liquefaction observed in the field was detectable with panchromatic instruments in particular. In the case of the Izmit earthquake, comparison of before and after images for both panchromatic and ERS SAR data demonstrated accurate detection of heavily damaged structures, although the cause of damage, whether ground failure (liquefaction) or severe shaking, could not be differentiated.

Tobita et al. (2002) discussed the use of InSAR data, together with basin models, to estimate the liquefaction susceptibility of earthquake-prone local areas as a function of the saturation of the upper 20 m of the subsurface. Bawden et al. (2001) have shown the ability of geodetic data (InSAR and GPS) to detect surface deformation due to groundwater discharge and recharge in local basins in the Los Angeles region. Integration of tectonic and hydrologic modeling is needed and recommended to resolve tectonic deformation that is occurring against the noise background of hydrologic variations at similar scales and amplitudes. Further, such an integrated model will contribute to identifying and scaling liquefaction hazards to determine the total seismic hazard. These studies will also provide useful information on the natural periods of soil sites for earthquake site response analysis.

Requirements

For detection of major liquefaction events, and major building damage during disaster response efforts, resolution of 10 m optical and 15 m SAR is acceptable. A smaller pixel size would enable a more complete assessment of ground failure and structural damage. For rapid earthquake response, revisit times of less than one day are best, both in terms of the response time and the quality of the damage maps. For liquefaction susceptibility and earthquake site response studies, subcentimeter resolution of surface change at spatial scales of tens of kilometers with revisit times on the order of a few days would be needed.

5. Are there non-seismic precursory phenomena that may enable and improve earthquake prediction?

There are numerous geophysical phenomena other than surface deformation that have been associated with seismic events.These include: very low-frequency (VLF), ultra low-frequency (ULF), and extremely low-frequency (ELF) magnetic fields observed on the ground and in space, high-frequency electric fields (including earthquake lights), and thermal anomalies observed with satellite sensors. There are individual events, such as the 1989 Loma Prieta earthquake ELF magnetic field, or the warming observed coincident with the Hector Mine earthquake, that appear significantly correlated with seismicity. But controversy remains regarding the statistical significance of the relationship of these anomalous signals to seismic events, particularly as earthquake precursors. The very small number of occurrences of these phenomena that are properly referenced to background noise, and which have a clear spatial and temporal relation to specific earthquakes, confounds a systematic approach to investigating the possible sources.

An unusual and unique thermal warming was observed by Landsat just 18 hours prior to the Hector Mine earthquake of October 16, 1999 near the Hector Mine fault break (Crippen, 2002). Comparison of the October 15, 1999 scene to the September 29, 1999 preceding scene shows that greatest warming in a zone that intersects the Hector Mine fault break (Figure 1.2). Limited Landsat coverage of the same region does not reveal a similar pattern for the Landers earthquake (1992), but no scene was acquired within 14 days of the Landers quake, and the spatial and radiometric resolutions and repeat coverages were inferior in the earlier Landsat satellites. The Hector Mine warming has also been reported in GOES geosynchronous weather satellite data through a series of images taken every 30 minutes at 5-km resolution. They show an unusual (but subtle) heating trend a few hours before the earthquake.

Earthquake-associated thermal “anomalies” have previously been reported by others, but without the spatial or temporal clarity of “signal” possibly indicated by the Hector Mine observations. Thermal emissions associated with earthquakes have been attributed to changes in fluid flow near fault zones resulting from rupturing of flow barriers as the crust approaches its yield strength (e.g., Hamza, 2001). While pressure-driven fluid flow within a shallow fault zone could generate a thermal anomaly of the scale and amplitude observed, a high permeability of the affected layers would be required for a precursory signal within one month of a main shock (E. Ivins, personal communication, 2003). This mechanism has been proposed as a means of generating both thermal and electromagnetic anomalies associated with the Loma Prieta earthquake (Fenoglio et al., 1995). To date, no clearly quantified relationship has emerged between thermal emission signals and earthquakes, either preseismically or coseismically. If thermal anomalies precede earthquakes by hours to days, satellite observations will require both high temporal (hourly) and high spatial (< 100 m) resolution to capture the signal.

Precursory quasicontinuous electric and magnetic fields associated with earthquakes, when they can be confidently observed, appear to arise from electrokinetic effects of fluid flow (Fenoglio et al., 1995; Park, 1996). Coseismic signals observed near the epicenter may reflect piezomagnetic effects (Johnston, 1997). Whereas a strong signal was observed by Magsat at 4 Hz for a M 7.2 earthquake in Tonga in 1980, a search for magnetic field signals of recent earthquakes using three currently orbiting high-precision magnetic field satellites did not identify any promising correlations (Taylor and Purucker, 2002). The mechanism proposed for Loma Prieta, invoking the motion of a conductive fluid resulting from rupture of impermeable layers, has also been proposed to explain transient thermal anomalies. Progress in understanding the relationship of electromagnetic and thermal emissions to the earthquake cycle requires high-quality, frequently updated observations, and verifiable models that satisfy multiple observational constraints.

Requirements

High spatial (< 100 m) resolution thermal measurements between 3 and 15 microns, updated hourly to daily, are needed to capture putative ephemeral thermal anomalies associated with earthquakes. Continuous magnetic and electric field measurements at DC to 800 Hz frequency are needed to test whether variations are correlated with seismic activity. Most importantly, these signals must be systematically isolated from natural background noise in a consistent manner, and evaluated simultaneously with crustal stress inferred from surface deformation measurements and fluid motion in the crust inferred from time-varying gravity.

The detailed science requirements discussed above constitute a complete set of observations that contribute to understanding earthquake physics and the earthquake cycle. However, consistent with the recommendations of the SESWG report and the wider community, we have focused our mission architecture on observing surface deformation, as this is deemed the highest payoff measurement to study earthquake physics. We focus on InSAR rather than LIDAR for three reasons. InSAR is an all-weather capability that can efficiently map the globe using a wide swath. It also measures topographic change to fractional wavelength accuracy. Its major limitation is in dense vegetation, and loss of correlation due to major surface disruption or vegetation change unrelated to tectonics. LIDAR can provide very precise "bare-earth"

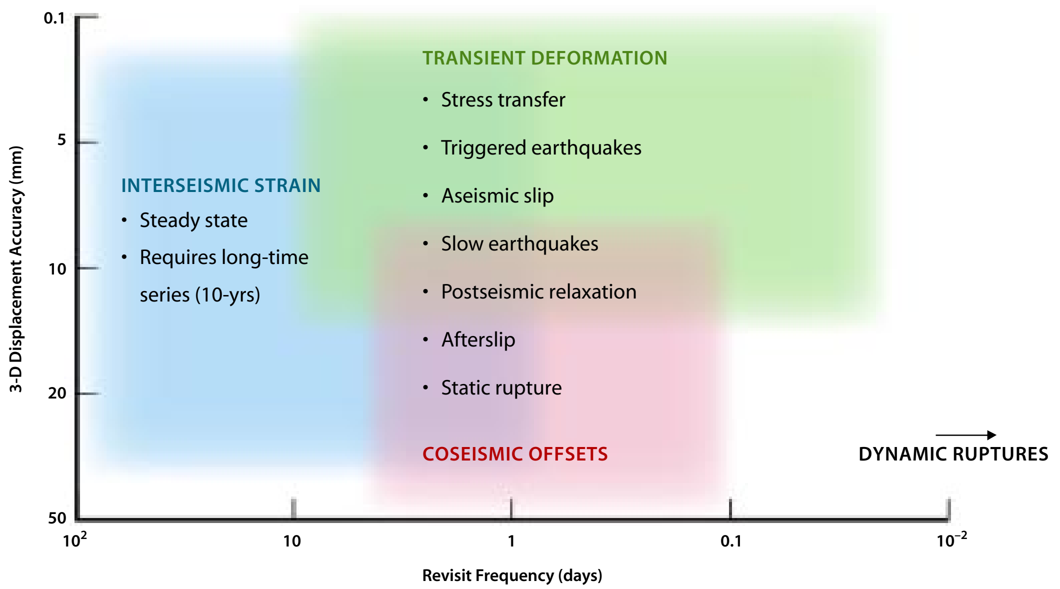


Figure 2.7
Science measurement requirements for surface displacement.

topography beneath vegetation. Its limitations are inoperability in cloudy air, a narrow footprint, and less-precise surface change detection. The InSAR technique has clear advantages for measuring long-term surface deformation globally. However, the LIDAR technique is likely to be important for local and regional-scale surveys of paleoseismic landforms, and for change detection beneath vegetation canopy.

The derived requirements for monitoring surface deformation are summarized on the science roadmap of Figure 2.7.

Disaster Management

A Global Earthquake Satellite System could contribute to managing earthquake disasters in two ways: by enabling higher spatial and temporal resolution hazard maps, and by providing timely and valuable information following an earthquake. Hazard assessments are currently used proactively to guide both building codes and disaster preparedness. Spatio-temporal granularity of hazards assessments would allow prioritizing of retrofitting projects according to relative seismic risks. Similarly, emergent behavior of a fault system indicating increasing potential for fault rupture would allow preparations to focus on specific geographic areas and infrastructure assets. In a post-event scenario, GESS would provide maps showing major damage and mapping peak accelerations to accurately assess the magnitude of the damage and guide first-response teams. It would also provide data for real-time mapping of changes in stress on neighboring fault systems to assess potential triggered seismicity.

The needs of the disaster management community drive the latency requirements for downlinking data and producing data products. Data must reach the ground very quickly, and be processed into interferograms within hours of an event to maximize its effectiveness. Direct downlink to users and a distributed processing environment enable this scenario. Data and data products must be released immediately on the Web, and online catalogs of recent data acquisitions, interferograms, and deformation time series must be maintained to expedite processing. Near-line archives of a decimated complete data set are also required to facilitate new analyses. Maps would be produced showing areas where the radar returns have decorrelated to indicate changes in the built environment, as well as maps of peak accelerations showing locations of major damage.

A robust community modeling environment is necessary to support the disaster management community. The community model would provide a sanctioned way to identify emergent behavior of a fault system and adjust hazard maps. Processing of data would be expedited following anomaly detection (precursors), and ground networks deployed to further investigate and monitor fault behavior. Following an event, the model would produce an estimate of the new stress field.

The customers for this information are anticipated to be the USGS, the Federal Emergency Management Agency (FEMA), California Office of Emergency Services (CA OES), local governments, and schools. Enlightening the general public to the dynamic nature of crustal deformation and therefore the hazards they must live with should lead to greater overall preparedness and thus fewer losses.

National Aeronautics and
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Jet Propulsion Laboratory
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Pasadena, California

JPL 400-1069 03/03